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ABSTRACT

This publication provides guidelines for teachers using the Aerospace Education II series publication entitled "Theory of Aircraft Flight." The organization of the guide for each chapter is according to objectives (traditional and behavioral), suggested outline, orientation, suggested key points, suggestions for teaching, instructional aids, projects, and further reading. A separate sheet is attached at the end of each chapter for teacher ideas for improvement of the chapter. Specific suggestions have been made throughout the guide for the major concepts. Page references corresponding to the textbook are made where appropriate. (PS)

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FEBRUARY 1975

AE-II

INSTRUCTIONAL UNIT I

THEORY OF AIRCRAFT FLIGHT

WRITTEN BY

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SE 019 339

AE-II - COURSE CONTENT

COURSE LEVEL OBJECTIVES - Each student should:

a. Know the major factors which affect aircraft design.

b. Know how aircraft engineers have taken advantage of advanced design technology to make aircraft more efficient.

c. Know the major design characteristics of aircraft engines.

d. Know the effect advanced aircraft engine design has on improved air travel.

e. Know the basic elements of air navigation.

f. Know how to use the simpler aids to air navigation.

g. Know the status of civil aviation.

h. Know the effect civil aviation has on our society and the problems yet to be solved.

i. Understand the role of military aerospace in our society.

INSTRUCTIONAL UNITS IN AE-II:

I. Theory of Aircraft Flight

II. Propulsion Systems for Aircraft

III. Air Navigation

IV. Civil Aviation and Facilities

V. Military Aerospace

FEBRUARY 1975

INSTRUCTIONAL UNIT I

THEORY OF AIRCRAFT FLIGHT

INSTRUCTIONAL UNIT OBJECTIVES - When the book is completed each student should:

a. Be familiar with man's early attempts to fly.

b. Know the basic physical laws which apply to aircraft flight.

c. Know the properties of the atmosphere which are important to aircraft flight.

d. Know the forces acting upon an airplane in flight.

e. Be familiar with aircraft stability and how it is affected by aircraft controls.

f. Know how aircraft engineers have taken the basic physical laws and the characteristics of the atmosphere into account when designing aircraft.

g. Know the importance of aircraft instruments to safe flight.

INSTRUCTIONAL UNIT I CHAPTERS

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I.	Aerodynamic Forces	I-1
II.	Properties of the Atmosphere	I-12
III.	Airfoils and Flight	I-19
IV.	Weight, Thrust, and Drag	I-29
V.	Aircraft Motion and Control	I-38
VI.	Aircraft Structure	I-47
VII.	Aircraft Instruments	I-57

CHAPTER I - AERODYNAMIC FORCES

This chapter introduces the unit and places man's attempts to fly in historical perspective. The student should realize that the Wright brothers' achievement depended on the experience of many centuries. Once the student has this sense of history firmly in mind, he can then examine the evolution of certain other physical laws in order to see how these laws affect aircraft in flight. Finally, he can take a quick look at an aircraft in flight in order to see how both history and physical laws help explain why the aircraft stays aloft.

1. OBJECTIVES:

   a. Traditional - Each student should:

      (1) Be familiar with man's early attempts to fly.

      (2) Know Newton's Laws of Motion.

      (3) Know how Bernoulli's Principle applies to aircraft flight.

      (4) Be familiar with the forces affecting an aircraft in flight.

   b. Behavioral - Each student should be able to:

      (1) Give at least three examples of man's early attempts to fly.

      (2) State each of Newton's Three Laws of Motion and give an example of each.

      (3) Describe how Bernoulli's Principle applies to aircraft flight.

      (4) Name each of the four forces that affect an aircraft in flight.

2. SUGGESTED OUTLINE:

   a. Man's early theories and myths about flight.

      (1) Grecian Legend - an attempt to explain why birds fly and man does not.

      (2) Archimedes' Experiments - concluded that things lighter than air will float in the atmosphere.

b. Early manned flying attempts

(1) Pre-Christian Chinese Period - Chinese man-flying kites; battle observation.

(2) Leonardo da Vinci - designed forerunners of the parachute and a helicopter which lacked a power source; ideas dormant until recently.

(3) Bird observation - observing birds in flight proved to be the clue to the secret of flight.

(4) George Cayley - 19th Century Englishman; built the first true model glider.

c. Twentieth Century advances

(1) Emergence of the combustion engine.

(a) Primary source of power in the 20th century.

(b) Samuel Langley - one of first to build a powered aircraft.

(2) Introduction of the dirigible - a steerable airship; competed with heavier-than-air aircraft for superiority in the early part of century.

(3) Wright brothers - Orville and Wilbur, combined all the previous knowledge to make the first successful controlled, powered, heavier-than-air aircraft flight.

d. Physical laws underlying flight

(1) Basic principles of flight; heavier-than-air craft fly because their airfoils lift and support their weight in flight as thrust is created which overcomes the resistance of air (drag).

(2) Sir Isaac Newton's (1642-1727) Laws of Motion

(a) Law of Inertia - "a body continues in its state of rest or uniform motion in a straight line unless an unbalanced force acts on it."

(b) "The acceleration of a body is directly proportional to the force exerted on the body, is inversely proportional to the force exerted on the body, is inversely proportional to the mass of the body, and is in the same direction as the force."

(c) "Whenever one body exerts a force upon a second body, the second exerts an equal and opposite force upon the first body."

(3) Terms and explanations of Newton's Laws.

(a) First Law.

1. Acceleration - the change in speed per unit of time in a given direction.

2. Velocity - the rate of motion in a given direction.

(b) Second Law.

1. Force - Power or energy which possesses both magnitude and direction and is exerted against a material body in a given direction.

2. Mass - quantity of matter in a body.

3. Weight - pull of gravity on that quantity of matter.

(c) Third Law - for every action there must be an equal and opposite reaction.

(4) Daniel Bernoulli - 18th century Swiss scientist.

(a) Discovered the principle that as velocity of a fluid increases its pressure decreases.

(b) Venturi Tube - narrower in the middle than at ends; this restriction causes a decrease in pressure - an application of Berroulli's principle.

e. Forces of flight

(1) Lift, weight, thrust, and drag - opposing forces must be in balance with one another when an aircraft is in straight and level, unaccelerated flight.

(a) Lift - operates to overcome weight.

(b) Weight - force pulling the aircraft toward the earth.

(c) Thrust - force giving motion to aircraft.

(d) Drag - force that opposes thrust or forward motion of the aircraft.

3. ORIENTATION:

The relationship between history and flight science.

(1) The first part of this chapter reviews the historical developments of man's quest for successful flight, but not in the detail or depth pursued in Aerospace Education I.

(2) The justification for the brief review is to reinforce your students' recall of the historical developments of aviation and various types of flying craft in order that they may gain an understanding as to why men fly. In this manner we make the transition from the historical development of aviation to the theoretical principles of flight and the physical laws which govern them.

4. SUGGESTED KEY POINTS:

(NOTE: Many page references cited in this handbook may not concide with the exact pages of your reference books. Many reference books have been revised several times since AFJROTC started in 1966.)

a. We take the student back in history to the myths and legends related to man's desire to fly. We show that there were undoubtedly some grains of truth and fact contained in them and that the pyramid of legends and experiences gradually enabled man to realize his dream.

*** V-9002, pp 1-4
** V-9014, pp 11-37
*** V-9156 (1973 ed.), pp 626-9
*** V-9198, (The Flying Machine), pp 1-4

b. As man observed the air space around him and such natural phenomena as smoke rising and the flight of birds, he became aware that his basic problem was to build an airship which was lighter than a like volume of air.

c. Since satisfactory power sources for heavier-than-air craft weren't available, the Montgolfier brothers introduced balloon flight. Continuous progress and success with balloons revitalized and stimulated man's interest in flying.

** V-9002, pp 4-8
** V-9014, pp 36-69
*** V-9156, pp 629-40

d. The student should be brought to recognize that the true pioneers of flights were the nineteenth century experimenters who laid the real foundations for controlled, powered, heavier-than-air flight.

** V-9002, pp 10-13
*** V-9014, pp 78, 80-84
*** V-9156, pp 640-4
** V-9157, pp 8-13

(1) Among these stand out such notables as George Cayley who constructed the first true model glider, and John Montgomery and Otto Lilienthal who recognized the need for an understanding of bird flight and the controlling of gliders.

e. The late 19th and early 20th centuries saw the emergence of the combustion engine. Much of its development was clouded by history and time. One of the first to build an aircraft and power it with an internal combustion engine was Samuel Langley, Secretary of the Smithsonian Institute.

*** V-9014, pp 84-88
** V-9156, pp 644-5

(1) During the early part of the century we saw the dirigible balloon or airship competing with heavier-than-air ships for superiority. However, as engine horsepower and aircraft design developed, the dirigible lost out due to the advantages of greater maneuverability and speed of airplanes.

** V-9014, pp 70-71, 124-125
** V-9156, pp 639-40, 711-12
** V-9002, pp 13-15
** V-9005 (1971 ed.) pp 12-13

f. The foresight of the Wright brothers in taking advantage of all previous research and in finally achieving the first successful "controlled," "powered," and "heavier-than-air" aircraft flight catapulted us into the aeronautical age.

*** V-9014, pp 85-87, 106-109, 114-115
** V-9156, pp 645-6

g. Physical laws underlying flight

(1) In this section of our chapter, we deal with the principles of aerodynamics and the physical laws that apply to them. The students must acquire a solid foundation in Newton's Laws of Motion and Bernoulli's Law of Pressure Differential before progressing further into the subject of aerodynamics.

** V-9002, pp 38-40
** V-9013, pp 43-4
** V-9065, pp 13-16, 22, 44-5

(2) In applying Newton's Laws to the principles of flight, we will want to consider velocity as the rate of motion in a given direction and acceleration as the change of rate of motion in a given direction per unit of time. The latter two terms comprise Newton's First Law of motion.

(3) In considering the Second Law which deals with force and mass, we think of force as being "power" or "energy" which has magnitude and direction and is exerted against a material body in a given direction. Mass is the quantity of matter in an object. We can then combine these ideas into a formal statement. "The rate of change of motion of a body is directly proportional to the power or energy exerted against this body, is inversely proportional to the quantity of matter in this body, and is in the same direction as the power or energy exerted against this body."

*** V-9023I, pp 13-16, 20-24

(4) The Third Law - for every action there must be an equal and opposite reaction - is essential in arriving at our composite summary of Newton's Laws.

(5) Bernoulli's discovery of the principle that as velocity increases, its pressure decreases is a primary key to powered combustible flight. The latter principle is utilized in the Venturi Tube, an important part of any carburetor. The Venturi Tube is narrower in the middle than it is at the ends. The Venturi effect causes fluid passing through such a tube to speed up as it reaches the middle. This results in less energy for the exertion of pressure, causing a decrease in pressure. The effect is known as Bernoulli's Law of Pressure Differential.

5. SUGGESTIONS FOR TEACHING:

a. Suggested time: 1-2-3 (Translation--if you teach two academic periods per week we recommend you devote one hour to this subject. If you teach three periods per week you could devote two periods. If you teach four academic hours per week you could devote three periods to the subject. These "Suggested times" are just that--recommendations. Adjust the emphasis according to interest and talent--both yours and the students'.)

b. Motivation. Because the student has already been exposed to aviation history in his first year, you will have to do some stage setting to revive his interest for the initial introduction of the chapter. If substantial public or school library facilities are available, you might establish a book display corner which would cover reading material that would supplement the resource material recommended in your key points. Another possibility is to prepare a bulletin board which depicts the historical advances in flying craft, but which is also labeled with captions to show how these advances have extended the use of the physical principles of flight relative to Newton's Laws of Motion and Bernoulli's Law of Pressure Differential.

c. In introducing the lesson, you should consider the wealth of support materials available for this text. The 5 minute FAA Film "Kites to Capsules" (see paragraph 6 below) would be an excellent interest stimulator. If you are lucky enough to have an opaque projector, there are numerous colorful historical pictures in your reference library books. After you have established flying as an interesting subject (which shouldn't

be too hard to do) you may effectively ask the students to compare aviation history to what they have learned in other courses. This discussion should include the significance of flight and the development of the principles of flight. Such a discussion should enable you to determine what your students already know about the subject. The student discussion can be effectively summarized by recording with the students the stages which depict the historical advances in aviation. NOTE: A pre-test could work well as a means of determining student knowledge about this instructional unit.

d. Another good method is to divide the class into groups and have each group research one historical phase. They can relate their assignment to the scientific principles of flight when they make their report to the class.

e. Throughout this instructional unit, there are many excellent opportunities to work with other instructors. For example, the instruction on Newton's Laws may be best accomplished by using the Physics instructor as a guest lecturer. The Chemistry Department should be contacted prior to covering Chapter II. For Chapter VI, you may want to have your students do some actual construction. The shop and vocational instructors should be able to offer valuable assistance. Under any circumstances, your instruction should supplement the instruction received in other classes on the same subject. You will "turn off" your better students very quickly unless you are aware of what they have already been taught about the subject. Use their knowledge to supplement your instruction.

f. If at all possible, you should review your plans for the entire unit of instruction prior to planning projects. For example, kite flying would be appropriate for Chapter I or III while paper airplanes are an excellent instructional aid for Chapter III. These same paper airplanes can be modified when studying aircraft control in Chapter V. If your students have not made model aircraft in AE-I, constructing models either for Principles of Flight in Chapter III or Aircraft Construction in Chapter VI would be appropriate.

g. Parts I and III of the FAA History of Flight series (see paragraph 6 below) should definitely be considered for this chapter in the event that your students did not see them in AE-I.

h. The Theory of Aircraft Flight unit of instruction can be quite a challenge to many of your students, but it should also be one of the most fun courses. As your grandmother used to say, "Why does man want to fly anyway? He should stay home and watch TV like God intended."

i. The next time the class meets, I would suggest you first discuss the physical laws affecting aerodynamics. The Physics instructor may assist you here. Following a discussion of the basic flight concepts, you could have your project committees take over and relate their findings to the class. Afterward, be sure to summarize with the class the key understandings that were derived from this chapter.

j. Answers to Chapter I Questions:

(1) Greeks

(2) Birds fly and man does not

(3) Leonardo da Vinci

(4) Smoke

(5) Stability and Steering

(6) John Montgomery, Otto Lilienthal

(7) (b) being one of the first to build an internal combustion engine

(8) More control, more power, higher speed

(9) True

(10) (answer - page 8 of text)

(11) 30 pounds

(12) Rate of motion in a given direction

(13) More energy is used up as the molecules accelerate, thus reducing the pressure

(14) False - Aviators should understand the principles of flight which contribute to safety and efficiency

(15) Lift - the upward force exerted on a balloon or airstrip; Weight - the force with which a body is attracted to the earth; Thrust - the driving force exerted on any aircraft; Drag - a resistant force exerted in a direction opposite to the direction of motion and parallel to the air stream

(16) True

(17) False

k. Student text assignment: read pages 1 - 12.

6. INSTRUCTIONAL AIDS

a. Films (NOTE: Asterisks denote film rating, e.g., *** = excellent, ** = good, * = fair or poor)

(1) USAF

SFP 506 Air Power - Fools, Daredevils and Geniuses, 27 min., B&W, 1957 (This is a better aid for AE-I, but effective if not already shown). ***

SFP 1222 High Flight, 2 min., color, 1963. ***

TF-1-5300 Beyond the Stick and Rudder, 14 min., B&W, 1959. **

TF-1-4805 How an Airplane Flies, 26 min., B&W, 1953 (Uses old aircraft and not too interesting - preview before showing). *

(2) FAA

FA-905 Kites to Capsules, 5 min., color, 1969. ***

FAN 105 History of Flight - Wright Brothers - Part I, 28 min., B&W, 1971. ***

FAN 106 History of Flight - Wright Brothers - Part II, 28 min., B&W, 1971. ***

b. Transparencies

V-1008A Forces Acting on an Aircraft in Flight

V-1030 Things at Rest (Units activated after 1971-72 will not have 1030 and 1031)

V-1031 Things in Motion

c. Slides

V-0086	Slide 12	(NOTE: The narrative and slides from series V-0101 may be appropriate for parts of this chapter depending on your plan of approach)
V-0087	Slide 4	

d. Miscellaneous

(1) Demonstration Aids for Aviation Education, compiled by CAP and reprinted by FAA, has some outstanding ideas for instructional aids. The ideas will be useful throughout this unit of instruction. This publication was distributed to all AFJROTC units.

(2) Most school libraries will have resource picture files that can be used to help you or your students prepare your bulletin board. It also is advisable to alert your students to bring in materials in order to build a resource file.

(NOTE: Some instructional aids will be listed for more than one chapter as they are appropriate as support in several areas.)

7. PROJECTS:

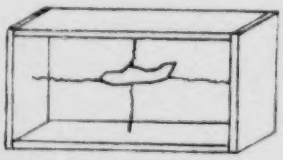
a. See page 11 of the text.

b. Rather than just reporting on the historical advancements of flight and their relations to the principles of aerodynamics, your students should be encouraged to make mobiles and mock-ups under the guidance of their art and industrial arts teachers. Be sure to coordinate with these staff members early enough so that they can integrate their planning and acquisition of materials with yours. Students should be encouraged to make materials for overhead and opaque projection when presenting their projects to the class.

c. Have each student report on at least one example of how Newton's Laws apply to students in everyday life.

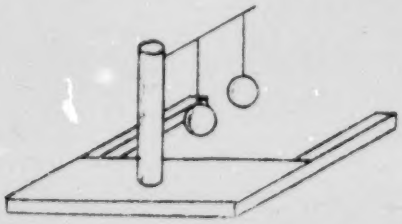
d. Find out if there are any members of the "Early Birds" or the "99s" in your area. They would be outstanding guest speakers.

e. Build a Forces of Flight demonstration model. Merely make a square wooden frame. Cut out a side view of an airplane, and suspend it with rubber bands inside the frame.



f. The December 1913 issue of Flying magazine has Orville Wright's own account of the Wright Brothers' first successful power-driven flight. Perhaps some of your students could locate this through the local library.

g. Build a model to demonstrate Bernoulli's Principle. (Also shown in the CAP booklet Visual Communications System by William J. Reynolds.) Using string, suspend two ping pong balls from a heavy wire. Using a straw, blow between the two balls and they will come together. By building a frame, this device can be used on the overhead projector.



8. FURTHER READING:

a. See page 11 of the text.

b. Aerospace Historian magazine.

c. Flying magazine.

d. Skylights. Published monthly by the National Aerospace Education Association, 1100 17th Street, NW, Suite 312, Washington DC 20036. Furnished to all members of the organization as a part of the annual $10.00 membership fee. It includes articles on aviation and aerospace developments and events.

e. Your Aerospace World, 1974, CAP (available through Bookstore, National Headquarters, CAP, Maxwell Air Force Base, Alabama 36112).

IDEAS FOR IMPROVEMENT OF THE TEXTBOOK AND/OR INSTRUCTOR'S GUIDE
AND TEACHING TECHNIQUES MOST EFFECTIVE FOR THIS CHAPTER.
TO BE COMPILED AT END OF TEXT AND SENT TO JRC

THEORY OF AIRCRAFT FLIGHT

CHAPTER II - PROPERTIES OF THE ATMOSPHERE

This chapter approaches flight from a different angle. Here, the student learns about the medium of flight - the atmosphere. The essential physical characteristics of the atmosphere are sketched so that the student will be able to understand subsequent sections of this unit.

1. OBJECTIVES:

   a. Traditional - Each student should:

      (1) Be familiar with the composition of the atmosphere.

      (2) Know at least four physical properties of the atmosphere.

   b. Behavioral - Each student should be able to:

      (1) Describe the atmosphere.

      (2) Identify some of the features of the atmosphere's layers.

      (3) Discuss at least four physical properties of the atmosphere.

2. SUGGESTED OUTLINE:

   a. The atmosphere: what is it?

      (1) Body of air which surrounds earth.

         (a) Consists of different layers, shells or spheres.

      (2) Definition of air - Mixture of gases in the atmosphere.

         (a) Nitrogen - 78.09%

         (b) Oxygen - 20.93%

         (c) Remainder - numerous substances in minute quantities - includes argon, water vapor, CO^2, dust, smoke, etc.

   b. Structure and composition of atmosphere as it affects flight.

      (1) Troposphere.

         (a) Lower layer, 5-10 miles thick.

         (b) The sun-warmed earth as a source of heat.

         (c) Most aircraft flight takes place in this zone from the surface to 26,000 feet at the poles and to 52,000 feet at the equator.

(d) This zone contains over 80% of our air (by weight). Molecules here cause more resistance to flying aircraft (drag) than in any other zone.

(2) Tropopause - Narrow border zone between the troposphere and the stratosphere. The jet stream (a high-speed, globe circling wind with 100-300 miles per hour winds) is located at or near the tropopause.

(3) Stratosphere.

(a) Zone which extends from the tropopause to about 264,000 feet above the earth's surface.

(b) Fairly constant frigid temperature in lower sections.

(c) Air is thinner in this region, so an airplane encounters less resistance from the air.

(4) Ionosphere - upper atmosphere.

(a) Contains few particles of air.

(b) Breakdown of gas particles because of electric discharges.

c. Physical properties of the atmosphere.

(1) Air is matter.

(2) Matter has weight and occupies space.

(3) Air occupies space.

(4) Air is a fluid.

(5) Air is compressible.

(6) Air exerts pressure.

(7) Pressure - force per unit area.

(a) Force - measured in pounds.

(b) Air pressure - measured in pounds (of force) per square inch (of surface area).

(8) Torricelli - Experiments with liquid mercury.

(a) Observed that air pressure (shown by rise and fall of mercury in a tube) changed as the weather changed.

(9) Standard pressure - amount of atmospheric pressure necessary to raise a column of mercury to 29.92 inches.

(10) Absolute pressure - pressure measured by means of a column of mercury.

(11) Relative pressure - reading relative to existing outside pressure.

(12) Density - mass per unit volume.

(a) Unit of mass - slug.

(b) Density decreases as height increases - the higher you go the less dense the air is.

(13) Air holds varying amounts of water vapor.

(a) Water vapor is water in a gaseous state.

(b) Water vapor weighs about five-eighths as much as a similar amount of air.

(14) Increasing the temperature of air decreases its density if the pressure is constant.

(a) A given volume of hot air weighs less than the same volume of cold air.

3. ORIENTATION:

a. This chapter underlines the importance of the atmosphere as a primary factor affecting the flight of aircraft. Much of the material is simply a review of material covered in AE-I.

b. It is important for the student to become acquainted with the composition and physical properties of the atmosphere in order to comprehend the problems encountered by aircraft, pilots, and passengers as they pass through the atmosphere at various levels.

c. Knowledge of these properties will improve the student's chances of understanding how planes fly when they progress to more complex subject matter dealing with the theory of flight in subsequent chapters.

4. SUGGESTED KEY POINTS:

**V-9002, pp 40-41
** V-9005, pp 99-100

a. An understanding of the atmosphere relative to its characteristics and elements of composition is an important factor in flight. We learn that the body of air which surrounds the earth consists of different layers or shells.

b. Air is a mixture composed of several substances.
***V-9013, pp 8-12
*V-9107, pp 1-3
**V-9156, pp 198-9
**V-9176, pp 12-13
*V-9013, p 4
Nitrogen accounts for 78.09% of air; oxygen for 20.93% and approximately 1% argon, hydrogen, carbon dioxide, carbon monoxide, and minute quantities of rare gases such as helium, krypton and zenon make up the balance.

(1) Air at low altitudes also contains varying amounts of water vapor, smoke and dust particles
**V-9107, pp 1-3
**V-9187, p MET-2-3

c. The composition of the atmosphere varies in different layers. The troposphere, which is the lower layer, is five to ten miles thick and contains over 80% of the air molecules. These molecules offer the greatest resistance to flying aircraft (drag).
**V-9013, pp 10-11
**V-9107, pp 1-3, 221-222
**V-9187, pp MET 1-7

d. Between the troposphere and the next layer, we have a narrow border zone known as the tropopause. The jet stream, which is a high speed globe circling wind achieving speeds of from 100 to 450 miles an hour, is at or near the tropopopause.
**V-9013, pp 10-11
**V-9107, pp 1-3, 221-224, 227

e. Above the tropopause we enter the stratosphere which extends approximately ten to 55 miles above the earth's surface and has fairly constant frigid temperature in the lower sections.
**V-9013, pp 11-15
*V-9107, pp 1-3

(1) The air is thinner in this region of the atmosphere and aircraft encounter less resistance from the air.

f. The upper atmospheric layer is known as the ionsphere and contains very few particles of air. The few particles found in this region are ions (charged gas molecules) which give us electrical manifestations such as the Northern Lights.
**V-9013, pp 12-13

g. To date, of all the layers of the atmosphere, the troposphere is most important because most aircraft fly within this zone and most weather occurs here.
*V-9107, pp 221-222

h. Air, a name conveniently used for atmosphere, has several important physical characteristics: it is matter; it is a fluid, it is compressible; it exerts pressure; it can hold varying amounts of water vapor; and it is affected by changes in temperature.
*V-9103, pp 10-11
*V-9107, pp 3-14
*V-9156, pp 212-213
***V-9176, pp 9-12, 61-63

i. The weight of air and its density varies. At normal sea level the pressure is approximately 15 pounds per square inch. As you climb upward in the atmosphere, the air becomes colder, thinner and lighter and at 18,000 feet the pressure is only half of that found at sea level.
*V-9103, pp 9-11
**V-9156, pp 199-203
***V-9176, pp 23-37 48-53

***V-9187, pp MET-7-10

(1) These variations in atmospheric pressure affect pilots, passengers, engines, and the plane itself.

(2) Decreased pressure has a definite effect on takeoffs and landings, rates of climb, air speed, and fuel consumption.

5. SUGGESTIONS FOR TEACHING:

a. Suggested time: 1-2-3 (Translation--if you teach two academic periods per week we recommend you devote one hour to this subject. If you teach three periods per week you could devote two periods. If you teach four academic hours per week you could devote three periods to the subject. These "Suggested times" are just that--recommendations. Adjust the emphasis according to interest and talent--both yours and the students'.)

b. Much of this chapter is a review of Aerospace Environment. You should know how extensively you have already covered this material and adjust the emphasis accordingly.

c. Science or Chemistry teachers may already have covered this material in their classes. As you discuss your instruction plans with them, they should be able to offer several additional ideas. Also, if you decide to conduct any of the numerous experiments available, you will undoubtedly want to borrow materials and supplies from the Science Department.

d. Demonstrations of the properties of air are very effective. In addition to the ideas listed in the resources for this chapter you can (1) place partially inflated balloons over the tops of two pop bottles, place one bottle in ice and the other in hot water; (2) submerge an inflated balloon in water, (3) demonstrate different fluid densities by dropping mercury into a beaker of water; (4) release two balloons - one filled with helium and the other with air; and (5) place an uninflated balloon on one side of a balance scale and an inflated balloon on the other.

e. Answers to Chapter II Questions:

(1) Atmosphere

(2) Troposphere, stratosphere, and ionosphere OR lower atmosphere, middle atmosphere, and upper atmosphere

(3) The mixture of gases in the atmosphere

(9) True

(10) d. all of the above

(11) Substances which may be made to change shape or to flow by applying pressure to them

(12) Pressure

(4) Oxygen

(5) troposphere or lower atmosphere

(6) The tropopause

(7) 10 to 55

(8) Ionosphere or upper atmosphere

(13) Air pressing on the mercury in the dish balanced the weight of the mercury in the tube. About 30"

(14) False (you are measuring relative pressure)

(15) Less

(16) Less; lighter

(17) Increases

f. Student text assignment: read pages 13 - 23.

6. INSTRUCTIONAL AIDS:

a. Films:

(1) FAA: FA-603A Density Altitude, 29 min., color, 1966. ***

(2) See pages 18 - 19 of V-9175c and V-9176c.

b. Transparencies:

(1) V-1026 Air Slows Satellites

(2) V-1034 Regions of the Atmosphere

(Units activated after 1971-72 will not have these items)

c. Slides:

(1) FAA AP-1 "The Atmosphere," 58 slides with a 23 min. sound tape, 1965.

(2) V-0087 Aircraft in Flight, slides 1 and 2.

d. Miscellaneous:

(1) Demonstration Aids for Aviation Education, CAP, pp 2-8, 21-33.

(2) V-9176, pp 9-13, 23-37, 48-53, and 61-63.

(3) Most encyclopedias contain ideas for experiments to demonstrate the various properties of air.

7. PROJECTS:

a. See page 22 of the text.

b. Have your students devise and perform additional experiments to demonstrate the properties of air.

8. FURTHER READINGS:

a. See page 22 of the text.

b. Aircraft in Flight, CAP.

c. Most encyclopedias have excellent sections on this subject. Many of them such as Compton's and the World Book also include excellent suggestions for experiments and demonstrations.

d. Your Aerospace World, 1974, CAP.

IDEAS FOR IMPROVEMENT OF THE TEXTBOOK AND/OR INSTRUCTOR'S GUIDE
AND TEACHING TECHNIQUES MOST EFFECTIVE FOR THIS CHAPTER.
TO BE COMPILED AT END OF TEXT AND SENT TO JRC

THEORY OF AIRCRAFT FLIGHT

CHAPTER III - AIRFOILS AND FLIGHT

This chapter is perhaps the most critical section of the entire unit. Chapters one and two have introduced the student to the physical laws underlying flight and also to selected physical properties of the atmosphere. This chapter then relies on this physical orientation to explain lift. An examination of the airfoil precedes a discussion of the interaction of wind and wing. The Venturi tube's evolution into the airfoil concludes the discussion of the generation of lift. The last section of the chapter discusses the ways in which lift can be varied.

1. OBJECTIVES:

   a. Traditional - Each student should:

      (1) Know the basic elements of an airfoil.

      (2) Know the difference between pressure differential and impact lift.

      (3) Know how lift can be varied and what happens as a result.

      (4) Understand the relationship of lift to the physical principles and properties of the atmosphere.

   b. Behavioral - Each student should be able to:

      (1) Describe at least three of the basic elements of an airfoil.

      (2) State the differences between pressure differential and impact lift.

      (3) Discuss how lift can be varied and describe what happens as a result.

      (4) Relate lift to the physical principles and properties of the atmosphere.

2. SUGGESTED OUTLINE:

   a. Definition of the term "airfoil"

   b. Study of airfoil design

      (1) Use of the wind tunnel to study airfoil design

      (2) Elements of an airfoil (leading edge, trailing edge, chord and camber)

c. Relative wind and angle of attack

(1) Angle of Incidence

(2) Attitude

d. Lift

(1) Bernoulli's Principle

(2) Newton's Third Law - impact lift

(3) Total lift

e. Variables affecting the amount of lift generated

(1) Angle of attack

(2) Speed of relative wind

(3) Air density

(4) Airfoil shape

(5) Wing area

(6) Airfoil planforms

(7) Devices such as flaps, slots, and spoilers

3. ORIENTATION:

a. This phase is based on the physical laws developed in Chapters One and Two. Newton's Laws of Motion and Bernoulli's Law of Pressure Differential are the steps leading to an understanding of the airfoil's ability to move through the air and generate enough lift to support the weight of the aircraft in flight.

b. Lift variables, either from design or under pilot control, are discussed. These variables have magnitude and can be calculated mathematically. It is up to you to recognize the math ability levels of your students and either go into problem solutions in depth, or to stay at a lower ability level. You may want to challenge your better students by using contracts or some other individualized technique.

c. An understanding of this chapter is important for the student because the next chapter deals with the other three forces acting on an aircraft while in flight.

4. SUGGESTED KEY POINTS:

a. The term and concept of "airfoil" are important and must be understood. It is more than just the wing of an aircraft. It includes any part of the aircraft that is designed to produce lift.

*V-9065, pp 13-18
***V-9118, (3rd ed.) pp 38-54
**V-9156, pp 14-16

b. The wing is the primary airfoil that lifts the aircraft in flight. In the design of airfoils, cross-sectional profiles are used. Both curvature and thickness are necessary to have an effective airfoil. To better understand these designs, it is important that the student understand the parts of an airfoil.

(1) The leading edge is the portion of the airfoil that first meets or bites the air. Its actual shape is determined by the purpose for which the airfoil will be used. It may be blunt for slow moving aircraft or very sharp for high speed aircraft.

(2) The trailing edge is that portion of the airfoil over which the air passes last. It is the edge where the airflow over the upper surface joins the airflow over the lower surface. When these two streams of air rejoin, the upper stream resumes the same speed as the lower. The trailing edge will take on an added dimension in Chapter IV when the supercritical wing is discussed.

(3) The chord of the airfoil is a reference line from which the upper and lower contours of an airfoil are measured. It is simply an imaginary straight line drawn through an airfoil from its leading edge to its trailing edge. This line is used as the reference line in measuring camber or curvature of the airfoil.

(4) The camber of the airfoil is the amount of curvature of the upper or lower surface with respect to its chord. The curve of the upper surface is referred to as the upper camber, and the curve of the lower surface is referred to as the lower camber. Usually the lower camber has less curvature than the upper camber, and it is this difference in curvature that leads to an increase in air speed over the upper surface of the airfoil, and a resultant decrease in pressure (Bernoulli's Principle).

c. The example of the student's hand out the car window is used to explain relative wind. At this point it is not important that the lift is primarily impact lift. The important factor is relating this knowledge to an airfoil moving through air. The airstream flowing around the hand (airfoil) is termed the relative wind. It is not air in motion. It is the motion of the aircraft through the air that produces it. This wind always appears to come from a point directly in front of the path of flight of the aircraft. Therefore, the direction of the relative wind is controlled by the pilot, as he controls the attitude or position of the aircraft. The attitude of the aircraft is its position in relation to the horizon. The pilot can change the angle at which the leading edge of the airfoil attacks the wind. This angle between the chord of the airfoil and the direction of the relative wind is termed the angle of attack. As the pilot increases the angle of attack, the lift also increases, as long as the flow of air continues to be streamlined. It is not necessarily important that the students understand attitude and angle of incidence, but it is very important that they understand that the aircraft can fly with a nose high attitude resulting in a large variance between relative wind direction and aircraft attitude or a very high angle of attack. Referring to the paragraph on page 30, it may help to point out that a climbing aircraft with a nose high attitude could have a 0° angle of attack, but the same attitude would result in a very high angle of attack if descending. Of course the relative wind would be different for all three examples.

***V-9002, pp 55-6
*V-9047, pp 76-79
**V-9089, pp 45-48
***V-9118, pp 39-44
**V-9156, pp 16-19 24
***V-9157, p 69
**V-9162, pp 5-6
**V-9166, pp 2-7
**V-9167, pp 9-15
***V-9187, pp AB-2-10

d. Remember that air is a fluid and that Bernoulli's Principle applies in fluids; "As the velocity of a fluid increases, its pressure decreases." Since the airfoil acts as part of a Venturi tube, the pressure above the airfoil is less than the pressure below the airfoil; and as a result, the airfoil is lifted or raised. The camber of the upper part of the airfoil causes the air passing over this part to travel at a greater speed than the air flowing past the much smaller camber of the lower part of the airfoil. The greater speed of the upper airstream results in the lower pressure above the airfoil and its resultant lift. This particular lift force is due to a difference in pressure and is termed a pressure differential lift. This lift acts in a direction opposite to gravity and perpendicular to

**V-9002, pp 51-54
*V-9118, pp 32-33
***V-9156, pp 11-15
**V-9162, pp 4-5

the direction of the relative wind. As this lift is being developed by the movement of the aircraft through the air, some of the airstream strikes against the underside of the wing. This air is deflected downward, and according to Newton's third law that to every force there is an equal and opposite reaction, the resistance or inertia of this air exerts a lifting force. This impact lift varies with speed and angle of attack. Normally it is much less than pressure differential lift. The two types of lift combine to produce total lift.

e. The pilot must be able to control the two types of lift acting on the aircraft. As mentioned earlier, the pilot controls angle of attack. As he changes this angle, he changes the amount of lift of the aircraft. Mathematically all the lift forces can be added together and the sum of these forces is termed the resultant. This resultant has magnitude (size), direction and location. The point where the resultant intersects the chord of the wing is termed the center of pressure (C/P). As the angle of attack increases, this center of pressure is moved forward and the lift increases until the burble point is reached. The burble point is the angle of attack where the streamlined flow of air begins to break down and become turbulent (burble). As the burbling increases, the amount of lift generated is no longer sufficient to keep the aircraft airborne. This point is termed the stalling point, and the aircraft begins to descend.

***V-9002, pp 55-58

**V-9118, pp 38-42

**V-9156, pp 20-22

f. Other key factors that affect the lift generated by an aircraft:

(1) The actual lift is directly proportional to the density of the surrounding air. It is proportional to the speed of the aircraft as well as the area of the wing. The denser the air, the greater the lift, all other factors being equal.

***V-9018, p 43

(2) The aircraft outline viewed from directly above or below is called a planform.

(3) The planform of the wing allows us to measure the aspect ratio. This is the span of the wing divided by the average chord of the wing (or the wing span squared divided by total wing area). Usually, the higher the aspect ratio, the more efficient the design of the wing.

V-9018, pp 41, 54, 56-57

(4) Flaps are devices for changing the camber of the wing. This can be done while in flight.

***V-9002, pp 65-67
***V-9089, pp 50-51
***V-9118, pp 63-64, 74
*V-9167, pp 24-27

(5) Slots are moveable or fixed sections of the leading edge of the airfoil. They also change camber and are used to smooth the airflow at high angles of attack.

**V-9002, pp 67-68
**V-9118, pp 65-66

(6) Spoilers are small surfaces either recessed into the upper surface of the airfoil or permanently fixed in a certain position. When raised, they "spoil" the airflow and lift is reduced. They may be rather large at the trailing edge and when raised serve as "air brakes."

5. SUGGESTIONS FOR TEACHING:

a. Suggested time: 3-4-5

b. In general, students should be interested in why and how an aircraft can fly. One method to consider is the lecture discussion method whereby students with some knowledge of aircraft flight can be encouraged to list known facts on the chalkboard. One introductory question could be, "why does an aircraft fly?" Another, to lead into a study of the airfoil, is "what is the most critical part of the aircraft?"

c. Students could be asked to construct paper airplanes, then fly them so that design differences can be analyzed. Model airplanes, paper airplanes, box kites, regular kites - all can be used by the instructor and students to demonstrate the key concept of what an airfoil is and what parts it contains.

d. Panels could be set up by the instructor using the above models, to help illustrate the factors affecting lift.

e. Student oral reports could be presented on such key items as:

(1) Use of the wind tunnel

(2) Shapes of airfoils

(3) Importance of the angle of attack

(4) Burble point and stalling point

(5) Flaps, slots, and spoilers

f. Depending upon the ability and needs of the students, you may want to construct some math problems concerning changes in some of the lift variables. The solving of these problems would give

the students a practical working knowledge of these factors. The physics instructor may be able to help you construct these problems. Aspect ratio problems can be devised easily by substituting different numbers in the formulas on page 38.

g. Refer to Figures 16 - 19 on page 34 of the text. Your sharper students may question the statements concerning climbing without a change in the relative wind. These pictures were drawn showing the flight conditions at the instant the situation happened. Obviously the relative wind would change to one from a more upward position in Figures 17 and 18. The condition in Figure 19, if allowed to persist would result in a rapid descent. You can test your students' knowledge of relative wind by asking them what would happen to relative wind in each instance.

h. While there are many excellent audiovisual materials available to support this chapter, you can supplement them by making additional transparencies or models. Plans for a wind tunnel which can be used on an overhead projector can be found on page 17 of William J. Reynold's VCS, Visual Communications Systems published by CAP and reprinted by FAA. If you are unable to get dry ice, fasten long threads to the inlet end of the wind tunnel. The threads will also demonstrate air flow visually on the overhead. There may be shop students looking for just such a project.

i. The first 30 frames of the Theory of Aircraft Flight Workbook (V-7201W) will serve as an excellent instructional aid and as an introduction to Chapter IV.

j. Textbook correction: "is" on page 29 should not be boldfaced.

k. Answers to Chapter III questions:

(1) airfoil

(2) False

(3) True

(4) leading edge, trailing edge, chord, and camber

(5) more

(6) trailing edge

(7) chord

(8) the characteristic curve of an airfoil's upper or lower surface

(15) True

(16) (d) all of the above

(17) lift

(18) magnitude, direction, and location

(19) the point of intersection of the resultant and the wing chord

(20) (d) all of the above

(21) forward

(9) relative wind

(10) False

(11) (d) attitude

(12) the force which acts perpendicular to the relative wind in an upward direction or the opposite of weight

(13) impact

(14) total lift

(22) it decreases

(23) stalling point

(24) directly

(25) greater

(26) greater

(27) planform

(28) statement of the relationship between the length and width of a wing

(29) False

(30) a. 2 b. 3 c. 1

1. Student text assignment: read pages 25 - 44.

6. INSTRUCTIONAL AIDS

a. Films:

(1) USAF

TF-1-0160 Aerodynamics - Air Flow, 18 min., B&W, 1941. **

TF-1-0161 Aerodynamics - Forces Acting on an Airfoil, 26 min., B&W, 1941. **

TF-1-4804 How an Airplane Flies, 26 min., B&W, 1953 (see note in Chapter I of this handbook). *

TF-1-5300 Beyond the Stick and Rudder, 14 min., B&W, 1959. **

TF-5521 Flying the Swept Wing, 24 min., color, 1963. **

(2) FAA

FA-703 How Airplanes Fly, 18 min., color, 1969. *** (might be better saved until Chapter IV or used as a transition)

b. Transparencies

V-1001 Airplane Components

V-1003 Wing Structure

V-1005A Lift

V-1005B Airflow Across Wings

V-1063 Parts of an Airfoil

V-1065 Forces of Flight (Lift)

c. Slides

V-0087 Aircraft in Flight - slides 3 through 7 and 9 through 11

d. Film Strips

Film strip No. 1, "Lift and Thrust" from the JAM Handy filmstrip series Aircraft - Their Power and Control. These can be purchased individually ($15.00 each) or as a set, with cassettes (#JH5960FC, $90.00) or records (#JH5960FR, $84.00) from: Scott Education Division, 104 Westfield Road, Holyoke, MA 01040. (They are highly recommended and should be purchased through your school library).

e. Miscellaneous

(1) Demonstration Aids for Aviation Education, pp 11-13.

(2) Activity cards 1, 2, 3, and 6 which are furnished with the JAM HANDY materials cited in 6.d. above.

(3) Battery Powered Cessna 150 Flying Model - available from: Cessna Aircraft Company, Air Age Education Department, P. O. Box 1521, Wichita, Kansas 67201.

(4) VFR Exam-O-Grams, 17, 27, and 47. A free set of Exam-O-Grams may be obtained from: FAA Aeronautical Center, Flight Standards Technical Division Operations Branch, P. O. Box 25082, Oklahoma City, Oklahoma 73125.

7. PROJECTS:

a. See pages 41 - 42 of the text.

b. Use the reverse cycle on a vacuum cleaner and a ping pong ball to demonstrate lift. Once the ping pong ball is suspended, you should be able to put the air stream at an angle and the lift will keep the ball aloft at an angle.

c. Demonstrate lift by placing a spool on top of a piece of paper and inserting a pin up through the paper into the spool hole. As you blow through the spool, lift will keep the paper on the bottom. Challenge some of your strongest boys to blow the paper off.

8. FURTHER READING:

a. See page 42 of the text.

b. V-9198

c. Aircraft In Flight, CAP

d. Aviation Week and Space Technology

e. Flying magazine

f. The TUSC News published by Technology Use Studies Center, Southeastern State College, Durant, Oklahoma 74701 (all AFJROTC units are on their mailing list).

g. Your Aerospace World, 1974, CAP.

IDEAS FOR IMPROVEMENT OF THE TEXTBOOK AND/OR INSTRUCTOR'S GUIDE
AND TEACHING TECHNIQUES MOST EFFECTIVE FOR THIS CHAPTER.
TO BE COMPILED AT END OF TEXT AND SENT TO JRC

THEORY OF AIRCRAFT FLIGHT

CHAPTER IV - WEIGHT, THRUST, AND DRAG

This chapter explains the other three forces acting on an aircraft in straight, level, and unaccelerated flight. After the student understands all the forces acting on an aircraft in straight, level, and unaccelerated flight, he can then move on to examine the three-dimensional aspect of aircraft flight.

1. OBJECTIVES:

   a. Traditional - Each student should:

      (1) Know how the "balance of forces" keeps an aircraft in the air.

      (2) Know how Newton's Third Law accounts for thrust.

      (3) Know the difference between induced drag and parasite drag.

      (4) Know how designers reduce turbulent flow drag.

      (5) Know the definition of supercritical wing.

      (6) Know how the four forces relate to helicopter flight.

   b. Behavioral - Each student should be able to:

      (1) Discuss how the "balance of forces" keeps an aircraft in the air.

      (2) Describe how Newton's Third Law accounts for thrust.

      (3) Differentiate between induced drag and parasite drag.

      (4) Outline how designers reduce turbulent flow drag.

      (5) Define supercritical wing.

      (6) Show how the four forces relate to helicopter flight.

2. SUGGESTED OUTLINE:

   a. Four forces maintain an aircraft in straight and level unaccelerated flight. These forces are lift, weight, thrust, and drag. Lift was covered in detail in the last chapter.

   b. Weight opposes the force of lift

(1) The total weight of the aircraft is caused by the pull of gravity

(2) The relationship of the center of gravity to weight and aircraft flight

c. Thrust drives the aircraft forward

(1) Reciprocating engines

(2) Jet engines

d. Drag opposes the thrust of the aircraft

(1) Induced drag

(a) Affects lifting surfaces

(b) Vortices

(2) Parasite drag

(a) Skin friction drag and boundary layer air

(b) Turbulent flow drag

(c) Streamlining to overcome drag

e. Supercritical wing

(1) Boundary layer air again

(2) Shock waves

f. Helicopters - affected by the same four forces

(1) Hovering

(2) Forward, sideward, or rearward flight all work the same

3. ORIENTATION:

a. This chapter covers the other three forces acting upon an aircraft in straight, level, and unaccelerated flight. The last chapter dealt with the forces of lift. This chapter will deal with weight, thrust, and drag. The supercritical wing is introduced in this chapter because the problems encountered are primarily related to drag. The helicopter is covered last because in this way it both covers an important area and serves as an excellent review of the forces of flight.

b. Once the student has a clear understanding of these four forces in an unchanging situation, he will be prepared to begin his study of the aircraft in motion in a three-dimensional sea of air.

4. SUGGESTED KEY POINTS.

a. The pull of the earth on the aircraft is responsible for the total weight of the aircraft. This pull of gravity is a force which acts in a direction opposite to the vertical component of lift. The further the aircraft mass is from the center of the earth, the less the pulling force of the earth on it. In other words, it weighs less. The force of weight acts vertically downward from the center of gravity (CG) of the airplane.

**V-9002, p 39
*V-9005, pp 18-19
*V-9065, p 22
**V-9118, p 44
**V-9156, p 27

b. Thrust is the force on an aircraft which gives it forward motion. It is related to Newton's Third Law of Motion. "For every action there is an equal and opposite reaction."

*V-9005, p 19
**V-9065, p 46
**V-9118, p 45
*V-9090, p 9
***V-9162, p 7

(1) Both jet and reciprocating engines operate as reaction engines.

(a) The reciprocating engine transmits the energy from the burning fuel through a complex system to the propeller. The turning of the propeller pushes a mass of air to the rear, and the reaction to this push (Newton's Third Law of Motion) moves the aircraft forward.

(b) The jet engine transmits the energy from the burning fuel directly out the exhaust system. The reaction to this force is against the walls of the combustion chamber, and it moves the aircraft forward.

c. Drag is the force which opposes the forward motion of the airplane. The total drag of the aircraft opposes its thrust. This total drag can be divided into two major types:

**V-9002, pp 59-65
*V-9005, p 19
*V-9013, pp 46-57
**V-9065, pp 20-22
*V-9118, pp 34-35, 37-38
***V-9187, pp AB-6-12
**V-9156, pp 28-29
**V-9162, pp 96-97
***V-9187, pp WT-1-9

(1) Induced drag is that part of the total air resistance caused by the lifting surfaces. It is an unavoidable result of lift, caused by the change in direction of the airflow resulting in the formation of trailing vortices from the wings. One of the ways the designer works to reduce this drag is by increasing the aspect ratio of the wing.

The pilot can control the magnitude of this drag by changing his angle of attack.

(2) Parasite drag is that part of the total air resistance caused by all the non-lifting surfaces of the aircraft. The movement of air over the skin surface of the fuselage and other fixed obstructions results in a friction loss termed skin friction drag. Closely related to this skin friction drag is the very thin layer of air moving next to the surface of the airfoil. This very thin layer of air becomes more turbulent as it passes from the leading edge of the airfoil to the trailing edge of the airfoil. It is termed boundary layer air. Also related to this is turbulent flow drag which is caused by anything interfering with the streamlined flow of air about the aircraft. Aeronautical engineers normally use the teardrop shape as often as possible in their designs. By doing this, air turbulence and the resultant drag is reduced.

**V-9156, pp 29-31

***V-9162, p 10

d. As high speed aircraft flew in the transonic and supersonic areas, the early separation of the boundary layer led to large shock waves and a loss of efficiency due to the reduced lift. The supercritical wing is merely one of many attempts to overcome this problem. At high speeds, the unique shape causes the boundary layer separation point to move farther back on the wing and reduce the shock wave size. Strangely enough, at transonic speeds, the boundary layer will adhere to the surface longer if it is slightly more turbulent.

**V-9118, pp 45-47, 68

**V-9156, pp 496-503

e. Helicopter flight is really simpler than aircraft flight if the students will accept the fact that the thrust of the propellor(s) has both horizontal and vertical components.

*V-9002, pp 390-6

***V-9013, pp 656-662, 668, 672-677

(1) Hovering means that both thrust and lift are parallel in a vertical plane and exactly equal to the sum of drag and weight.

***V-9118, pp 94-104 (4th ed.)

***V-9135, pp 7-10, 16-17, 19-27

(2) Climbing or descending straight up and down merely means that lift plus thrust is greater or less than drag plus weight respectively.

***V-9156, pp 166-172, 179-184

**V-9168, Plane 10

(3) Flight in any direction, forward, sideward, or rearward, is identical insofar as the four forces of flight apply. The resultant of lift and thrust, accomplished by tilting

the rotor, must be greater than the resultant of drag and weight. For example, if the horizontal component of lift exceeds drag and the vertical component of lift equals weight, the helicopter will travel in the horizontal direction of thrust at a constant altitude.

5. SUGGESTIONS FOR TEACHING:

a. Suggested time: 2-3-4

b. Introduce a study of weight by asking such questions as, "How did Newton explain the apple falling to the ground?" "How high up must we go to experience weightlessness?" The students can bring in discussion points learned from their science classes. Simple demonstrations can be performed by students or the instructor to develop the key points into student discussions. One such demonstration is to release a balloon in class to illustrate thrust.

c. As students begin to understand the four forces interacting on an aircraft in straight and level flight, problems can be presented to students for solutions. Students can be asked to predict what happens to the four forces in flight when the angle of attack is changed.

d. Oral reports by students can be assigned on such key items as:

(1) Newton's Third Law of Motion

(2) Reaction engines

(3) Induced drag and the aspect ratio

(4) Skin friction drag and boundary layer air

(5) Turbulent flow drag and streamlining

e. The supercritical wing will probably be too advanced for most of your students in which case you will want to either skip it or mention it as a new airfoil design. Several new designs are presently being studied such as the anti-symmetrical wing, the oblique wing, the "free wing" and the "flying wing." (See references below). A Piper PA 34 Seneca modified with a supercritical wing has already flown. Fuel economy improved up to 10% (TUSC News, December 1974). All of these areas are excellent possibilities for student research and reports.

f. Your students can also be assigned research reports depending on their ability. Your better students could find out what

the Reynolds Number is (see V-9118) and how it applies to drag. Others could report on laminar flow.

g. The last subject in Chapter IV on helicopters serves both as an excellent means of testing your students' grasp of the four forces of flight and as an introduction to vectors and resultants, which will be necessary for an understanding of the material in Chapter V. A good review would be to draw a direction of flight for a helicopter and have your students draw the appropriate vectors for weight, drag, thrust, and lift that would be required for that direction of flight.

h. It is possible that your students will be intrigued with helicopter flight. Be prepared to answer such questions as "How does the pilot change directions?" and "What happens when the engine quits?" For this last question, the simple autogyro mentioned on page 55 of the text will be helpful (see plans below).

i. Answers to Chapter IV Questions:

(1) Gravity

(2) (b) center of gravity

(3) force which drives the aircraft forward

(4) Reciprocating and jet engines

(5) The force which tends to retard an aircraft's progress through the air or the force which opposes thrust

(6) The change in direction of the airflow

(7) Retard; absorbing

(8) By reducing the area of the wing affected by wing tip vortices

(9) By decreasing the angle of attack

(10) All drag components except induced drag

(11) Skin friction drag and turbulent flow drag

(12) Boundary layer air

(13) More

(14) Keep the aircraft clean and well polished; removing surface irregularities

(15) Streamlining

(16) The teardrops

(17) Supercritical wing

(18) Impact

(19) True

(20) By changing the tilt of the rotor.

j. Student text assignment: read pages 45-56.

6. INSTRUCTIONAL AIDS:

a. Films:

(1) USAF

TF-1-4804 How an Airplane Flies, 26 min., B&W, 1953. *

TF-1-4805 How an Airplane Flies, 34 min., B&W, 1953 (probably more appropriate for Chapter V). *

TF-1-5300 Beyond the Stick and Rudder, 14 min., B&W, 1959. ***

TF-1-5340 High Speed Flight - Approaching the Speed of Sound, 27 min., color, 1959. ***

TF-1-5341 High Speed Flight - Transonic Flight, 20 min., color, 1959. ***

TF-5521 Flying the Swept Wing, 24 min., color, 1963. **

TF-5550 High Speed Flight - Beyond the Speed of Sound, 20 min., color, 1962. *

TF-6018 Helicopter Performance Data - Temperature Makes the Difference, 26 min., color, 1967. *

(2) FAA

FA-10-70 Caution: Wake Turbulence, 16 min., color, 1970. ***

FA-703 How Airplanes Fly, 18 min., color, 1969. ***

(3) Shell Film Library
450 North Meridian Street
Indianapolis, Indiana 46204

(borrower pays return postage - book at least 4 weeks in advance)

Approaching the Speed of Sound, 27 1/2 min., color, 1958. ***

Beyond the Speed of Sound, 19 min., color. ***

Transonic Flight, 20 min., color, 1959. ***

b. Transparency

V-1008A Forces Acting on an Aircraft in Flight

c. Slides

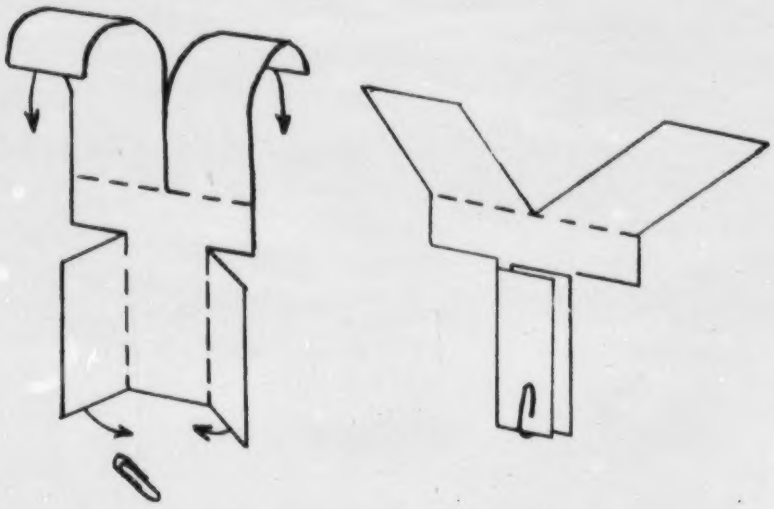
V-0087 Aircraft in Flight - slides 8, 9, 11-13, 21-25.

d. Film Strips

Filmstrip 1, "Lift and Thrust" and Filmstrip 3, "How Helicopters Fly" from the JAM HANDY series "Aircraft; Their Power and Control" (see Chapter III this handbook).

e. Miscellaneous:

(1) Autogyro. To construct it you need a rectangular sheet of paper (5" X 8" works well) and a paper clip. Cut (or tear) on the solid lines and fold on the dotted lines as shown below.



When you lift it up and let it go it should autorotate.

(2) Either the chalkboard or the overhead projector may be used effectively to explain the forces of flight. However, if you want something more permanent or professional, a flannelboard or a magnetic board are both very effective.

(3) Use the forces of flight model described in Chapter I.

7. PROJECTS:

a. See page 55 of the text.

b. Have your students conduct experiments that help explain weight, thrust, and drag. They should demonstrate them or report the results to the class.

c. Have your students find examples of how streamlining is used in everyday life, e.g., autos, boats, motorcycles, etc., and discuss the effect on operating efficiency.

d. VSTOL aircraft are not discussed in this text. Ask your students to report on the latest VSTOL developments and explain how the forces of flight apply.

8. FURTHER READING:

a. See page 55 of the text.

b. Aircraft in Flight, CAP.

c. Aeronautics, Space in the Seventies, NASA, 1971 (EP-85).

d. Aerospace magazine, published monthly by Aerospace Industries Association (September 1973, pp 8-13; September 1974, pp 11-16).

e. Airman's Information Manual, Part I, FAA (Section on Wake Turbulence).

f. Aviation Week and Space Technology (e.g., March 22, 1971, p 48; August 20, 1973, p 56; and November 25, 1974, pp 43-45).

g. Popular Mechanics magazine (March 1973).

h. Science Digest magazine (February 1974).

i. The TUSC News.

j. V-9110 (Helicopters and Autogyros).

k. Your Aerospace World, 1974, CAP.

IDEAS FOR IMPROVEMENT OF THE TEXTBOOK AND/OR INSTRUCTOR'S GUIDE
AND TEACHING TECHNIQUES MOST EFFECTIVE FOR THIS CHAPTER.
TO BE COMPILED AT END OF TEXT AND SENT TO JRC

THEORY OF AIRCRAFT FLIGHT

CHAPTER V - AIRCRAFT MOTION AND CONTROL

This chapter examines the aircraft in motion. Stability, climbing flight, and turning flight form a convenient framework for discussing the mechanics of aircraft in motion.

1. OBJECTIVES:

   a. Traditional - Each student should:

      (1) Know the three axes of rotation used to describe the movement of aircraft.

      (2) Know the resulting motion about these axes when an aircraft rotates in various planes.

      (3) Know the effects of lack of stability on the axes of rotation of the aircraft.

      (4) Know the concept of aircraft control and know at least three control surfaces.

      (5) Know which control surfaces affect which aircraft motions.

      (6) Understand rate of climb and angle of climb.

   b. Behavioral - Each student should be able to:

      (1) List the three axes of rotation.

      (2) Describe the resulting motion about these axes when an aircraft rotates in various planes.

      (3) Discuss the effects of a lack of stability for each of the axes of an aircraft.

      (4) Outline the concept of aircraft control and list at least three control surfaces.

      (5) State which control surfaces affect which aircraft motions.

      (6) Explain rate of climb and angle of climb.

2. SUGGESTED OUTLINE:

   a. Aircraft fly in three dimensions

   b. Axes of rotation - types of aircraft motion

      (1) Longitudinal axis - roll

(2) Lateral axis - pitch

(3) Vertical axis - yaw

c. Aircraft stability - central concept behind aircraft design, operation, and control

(1) Static stability

(2) Neutral stability

(3) Positive stability

(4) Negative stability

(5) Dynamic stability

d. Longitudinal axis stability - factors involved

(1) Intentionally noseheavy balance - location of Center of Pressure compared to Center of Gravity

(2) Effect of wind movement over the airfoils

(a) Downwash

(b) Slipstream

e. Lateral axis stability - factors involved

(1) Dihedral

(2) Keel effect

(3) Sweepback

f. Directional Stability

g. Aircraft control - how maintained

(1) Controls - actual devices regulating speed, direction, altitude, and power

(2) Control surfaces

(a) Ailerons - roll

(b) Rudders - yaw

(c) Elevators - pitch

(d) Trim tabs - fine tuning

(3) Climbing flight

(a) Reserve horsepower

(b) Power loading

(c) Climbing angle and rate of climb

(d) Service ceiling and absolute ceiling

(4) Aircraft turns - factors involved

(a) Effective lift

(b) Centrifugal force

(c) Angle of bank

(d) Skid

(e) Slip

(f) Effects of control surfaces in turns

h. Aircraft motion and control - effects of throttle and control surfaces

3. ORIENTATION:

a. The study of aircraft motion and control is based upon the background developed in Chapters III and IV. Aircraft are able to sustain flight when there is a balance among the forces of lift, weight, thrust, and drag. When one of the forces is too far out of balance, some control adjustment must be made or it will be impossible to maintain safe flight for very long.

b. This chapter looks at the aircraft once it is in flight. It deals with the axes of rotation and the movement the aircraft makes around these axes. It explains the concept of stability in flight. The chapter includes aircraft controls and the role they play in movement of the plane.

4. SUGGESTED KEY POINTS:

*V-9002, pp 83-84
***V-9187, pp AB-13-14

a. There are three types of motion other than straight and level flight. Aircraft can move around three axes of rotation: longitudinal (roll); lateral (pitch); and vertical (yaw).

b. Stability, an extremely important concept in aircraft design, is divided into two types: static - the aircraft's tendency to return to its original position and dynamic - the tendency to return to its original position with a minimum of restorative oscillations.

***V-9002, pp 80-92
***V-9005, pp 20-21
62-67
**V-9013, pp 62-65
***V-9156, pp 109-113

**V-9167, pp 65-70

(1) Longitudinal stability infers that an aircraft will not pitch unless some external force raises or lowers the nose of the aircraft. It is necessary to have a slightly noseheavy balance in order to have good longitudinal stability. Therefore, aircraft are constructed so that the Center of Gravity will be ahead of the Center of Pressure. This tendency to be nose heavy is overcome by downwash, a downward movement of wind on the tail of the aircraft.

(2) Lateral stability infers that the wing tips of an aircraft will hold their positions (the aircraft will not roll) unless acted upon by some external forces. Factors involved which maintain this stability are dihedral, keel effect, and sweepback.

**V-9156, pp 113-116

(3) Directional stability is the tendency not to yaw. It is determined by aircraft construction. The chief factor contributing to directional stability is the vertical fin and side area of fuselage behind the Center of Gravity.

***V-9156, pp 116-120

c. Controls refer to devices by which the pilot regulates his aircraft. These include ailerons, rudders, and elevators, all of which are moveable airfoils. Using these the pilot can change the attitude of the aircraft. Additionally, secondary control surfaces called trim tabs may be attached to these. Certain lift devices such as flaps, slots, and spoilers were discussed previously in the chapter on lift. These are sometimes considered when discussing controls.

**V-9002, pp 92-97
***V-9005, pp 21-24, 67
**V-9118, pp 70-74
***V-9122, pp 308-318
***V-9161, pp 2-1-5
***V-9187, pp AB-14-17

(1) Climbing flight is dependent upon reserve horsepower in the aircraft engine. Factors involved include rate of climb and angle of climb. Service ceiling, the altitude at which the maximum rate of climb is 100 feet per minute, and absolute ceiling, the altitude at which the aircraft ceases to climb, are both important factors involved in climbing.

***V-9002, pp 70-72

(2) Forces in turning involve the principle of centrifugal force. Turning factors such as angle of bank, skids, and slips can be more easily understood when you visualize lift in vertical and horizontal components.

***V-9002, pp 46, 70-72
***V-9005, pp 71-73
**V-9090, p 33
***V-9161, pp 1-30-31
***V-9162, pp 47-48

d. Aircraft motion is controlled by the throttle and the control surfaces. Through use of these controls, the pilot changes the balance between the four forces: thrust, lift, drag and weight.

**V-9002, p 92
**V-9047, pp 79-82
***V-9156, pp 120-123

(1) Throttle is the up and down control

(2) Elevators control speed

(3) Ailerons and elevators turn the aircraft

(4) Rudder corrects for adverse yaw.

5. SUGGESTIONS FOR TEACHING:

a. Suggested time: 4-5-5

b. Student text assignment: read pages 57 - 83.

c. The best suggested teaching method for this chapter would be a combination lecture, demonstration, and guided discussion. The theory of aircraft motion and control can best be demonstrated by use of a model airplane with moveable controls. The axes of rotation can be shown by inserting soda straws or some other device through the longitudinal, vertical and lateral axes of another simpler model with holes drilled through it. Discussion and demonstration of roll, pitch, and yaw could be developed along these lines. The instructor should use a hand-held model, moved in changing directions in his lecture on aircraft stability. Various movements and changes of direction could very well demonstrate these points. Perhaps you could have some shop students make several small simple models so that students would have a better chance to handle the model.

d. Some of the key points in this chapter are very difficult for students to grasp. You may have to use several different explanations in order to clear up confusion. Some possibilities are:

(1) Longitudinal axis stability is hard to visualize. Be sure to point out that the horizontal stabilizer is fastened on slanting down toward the front so that its' angle of attack is negative. Naturally, they should

come to understand that this whole setup is designed to achieve both static and dynamic stability.

(2) Stability may be compared to the balance of forces, i.e., a balance of the four forces of flight would be a static stable condition. Applying thrust would create an unstable condition, but drag and possibly a loss of lift would tend to bring the aircraft back to equilibrium - static stability.

(3) Some students will undoubtedly become confused when discussing movement about an axis, e.g., pitch about the lateral axis, only to find out that a resistance to pitch is stability along the longitudinal axis. Without a model, it will be impossible to make it completely clear for all students, however, you might equate their automobile to directional stability and yaw. If the front wheels are out of alignment, the steering may have negative stability along the longitudinal axis and about the vertical axis - directional instability. Stability refers to motion about one axis while moving the entire length of another axis. Longitudinal stability - if the nose goes down, the longitudinal axis is moved around the lateral axis; Lateral stability - if a wing comes up the lateral axis is moved around the longitudinal axis; directional stability - sideways movement of the nose along the longitudinal axis (the direction you're headed) about the vertical axis.

(4) Forces in turns, slips, and skids can be confusing. The most effective system I've seen is to divide lift into vertical and horizontal components with centrifugal force and weight counteracting them. Any vector or resultant out of balance with its' opposite counterpart will lead to a climb, descent, skid, or slip. A good quick way to test your students' comprehension is to have them complete the missing vector/resultants in Figure 43, assuming it's a coordinated turn.

(5) Some of you fighter types will surely take issue with the statement that the throttle controls altitude and the elevators airspeed. Before you enlighten your students with "the way it really is," remember that's the way it's taught in FAA flight training and that's the way it will be taught to them when they start to fly.

e. Some of your students may have gasoline-powered flying models. Have them put on a demonstration explaining the controls. Maybe they will let other students fly them.

f. Regarding question 5, page 81 of the text. The B-58 is a good example. Because the line of thrust on an outboard engine was

so far from the CG, if one suddenly failed at supersonic speeds, it would be possible to literally tear the aircraft apart due to the yaw. This can be stopped by installing a system whereby an outboard engine failure means an immediate automatic shutdown of the other outboard.

g. Frames 31 through 68 plus the review questions in the Theory of Flight Workbook (V-7021W) serve as an excellent aid for this chapter.

h. Modify the paper airplanes your students built earlier and put control surfaces on them. Have a contest.

i. Answers to Chapter V Questions:

(1) that the forces are in balance

(2) a. 2 b. 1 c. 3

(3) a. 1 b. 3 c. 2

(4) False

(5) Stability

(6) a. 3 b. 1 c. 2

(7) The tendency to return to an original position with a minimum of oscillation

(8) c. longitudinal

(9) Behind

(10) The slight downward movement given to relative wind passing over an airfoil

(11) Slipstream

(12) Lateral

(13) d. all of the above

(14) False

(15) More

(16) a. 3 b. 2 c. 1

(17) More

(18) False

(19) b. left

(20) The Frise aileron

(21) Moveable control surface attached to the vertical fin

(22) False

(23) False

(24) b. 220

(25) Stalling; maximum

(26) Time

(27) Service

(28) d. weight

(29) The angle between the aircraft wings and the horizontal

(30) a. 1 b. 2 c. 3

(31) to correct for adverse yaw

(32) "get that stick forward!"

6. INSTRUCTIONAL AIDS:

a. Films:

(1) USAF

SFP 1151 Crossover, 15 min., color, 1963. ***

TF-1-0700 Airplane Structures - Control Surfaces, 7 min., B&W, 1943. *

TF-1-4805 How an Airplane Flies, 34 min., B&W, 1953. *

TF-1-5300 Beyond the Stick and Rudder, 14 min., B&W, 1959. ***

TF 6129 Control Is a Greek Named Alpha, 20 min., color, 1967. *

TF 6155 F-4 Flight Characteristics, 18 min., color, 1968. **

(2) FAA

FA-07-03 Flying Boats, 19 min., color. **

(3) NASA

HQ 205 Space in the Seventies, 28 min., color, 1971. ***

b. Transparencies

V-1008B Airplane Roll, Pitch, and Yaw Axes

V-1009 Operation of Elevators

V-1021 Take-off Conditions (not issued since 1971)

V-1055 Runway and Approach Lighting System (better for V-7204)

V-1064 Control of Airplane in Flight

V-1066 Attitude and Attitude Control

V-1067 Control Devices

c. Slides

V-0087 slides 14 through 20

d. Miscellaneous

(1) "Controlling an Airplane" - JAM HANDY filmstrip No. 2.

(2) Demonstration Aids for Aviation Education, CAP, pp 14-16.

(3) VCS, Visual Communications Systems by William Reynolds - The plans for a moveable control model airplane are on page 17.

(4) Small airplane demonstration models with moveable controls. These can be made in your shop or purchased quite inexpensively through commercial sources in either paper or plastic versions.

(5) "U-Fly-It" Aircraft Model - Model Piper aircraft on a glide line with a control stick for landings. Available through Schaper Manufacturing Company, P. O. Box 1426, Minneapolis, Minnesota 55427.

(6) Flight Simulators. Your School Board may be willing to purchase one for your school. Several excellent models are available for sale or lease through commercial sources. Prices range from approximately $1,000 upward. Advise AFROTC/JRC if you are unable to locate information about simulators.

7. PROJECTS:

a. See page 81 in the text.

b. Have your students research and report on elevons, V-tails etc., and how they are used in aircraft control.

8. FURTHER READING:

a. Aircraft in Flight, CAP.

b. Current copies of Aviation Week and Space Technology.

c. VFR Exam-O-Gram No. 28 "Factors Affecting Stall Speed."

d. The TUSC News.

IDEAS FOR IMPROVEMENT OF THE TEXTBOOK AND/OR INSTRUCTOR'S GUIDE
AND TEACHING TECHNIQUES MOST EFFECTIVE FOR THIS CHAPTER.
TO BE COMPILED AT END OF TEXT AND SENT TO JRC

THEORY OF AIRCRAFT FLIGHT

CHAPTER VI - AIRCRAFT STRUCTURE

This chapter examines the aircraft itself. The major structural elements of the aircraft provide a good framework for discussions of stress, construction, and operation of selected aircraft components.

1. OBJECTIVES:

   a. Traditional - Each student should:

      (1) Know the major components of an aircraft.

      (2) Know at least three types of stress and their effects on aircraft components.

      (3) Be familiar with at least three types of elementary design structures and how they are used to give aircraft components strength without adding excessive weight.

      (4) Know various types and the principal parts of fuselages, wings, and empennage.

      (5) Know the primary applications of hydraulic and electrical systems in aircraft.

      (6) Know how todays aircraft landing gear works.

   b. Behavioral - Each student should be able to:

      (1) Describe the major components of an aircraft.

      (2) List at least three types of stress and discuss their effects on aircraft components.

      (3) Recall at least three types of elementary design structures and tell how they give an aircraft strength without adding excessive weight.

      (4) Discuss various types of fuselages, wings, and empennage and describe the principal parts of each.

      (5) State the primary applications of hydraulic and electrical systems in aircraft.

      (6) Describe how today's aircraft landing gear works.

2. SUGGESTED OUTLINE:

   a. The power plant (engine and propellers)

(1) Housed in engine cowling and nacelle

(2) Engine turns propeller

(3) Propeller creates thrust (Newton's 3rd Law of Motion)

b. Fuselage

(1) Main part of aircraft

(2) Houses crew, instruments, and payload (cargo, passengers, etc.)

(3) Two main types of fuselage construction

(a) Welded steel truss (steel tubing)

(b) Semimonocoque (internally braced metal skin)

(4) Five stresses acting on an aircraft in flight (stress is an internal force which resists applied outside force)

(a) Tension: Stress which resists attempt to pull apart (like stretching a rubber band - or the pull on the control cables of an aircraft as you move the stick)

(b) Compression: Opposite of tension - resists a force trying to push together (like squeezing a football from both ends - landing gear struts undergo compression)

(c) Bending: Combination of tension and compression - wing span (interior structure) undergoes bending during flight - lower side of spar is subject to tension while upper-side is subjected to compression

(d) Shear: Type of stress exerted when two items, such as metal bolted or riveted together, are pulled apart or pushed together by sliding one over the other. Bolts and rivets are designed to resist shear

(e) Torsion: Stress which resists being twisted apart (torsional force is produced when you turn the steering wheel of an automobile - or when the aircraft engine exerts a torsional force on the propeller shaft directly affecting the flight of the plane)

(5) General effect of stresses:

(a) All parts of aircraft are subjected to one or more stresses

(b) Usually act in combinations of two or more

(c) Sometimes alternate: tension followed by compression, etc.

(d) Some parts carry only one type of stress; e.g., wires and cables can carry only tension

(6) Trussed fuselages (used mostly in light civilian aircraft, liaison, observation, and training planes)

(a) Welded tubular steel structure

(b) Covered with fabric over fairing (streamlined)

(c) Acts like the structure of a bridge

(7) Semimonocoque (used in most military aircraft)

(a) Skin (usually sheets of aluminim alloy) and internal bracing carry the stress

(b) Easy to build in streamlined form

(c) Strength comes from metal skin reinforced by internal rings and stringers

(8) Load factor; Load placed on aircraft under various conditions of flight:

(a) Ideal: Aircraft is flying straight and level and load is evenly balanced

(b) Strain: climbing, diving, banking, turbulent weather

(c) Ultimate load: point of structural failure; usually 1 1/2 times the greatest load the aircraft structure will be subjected to in normal flight

(d) Maximum applied load - greatest load expected in flight

(e) Safety factor - ratio between maximum applied and ultimate loads

(f) Idea is to keep stress on any part from reaching ultimate load, while keeping the aircraft as light as possible

c. Wings

(1) Basic construction materials used are wood (covered with fabric) and metal

(2) Wooden wings

(a) Two long spars

(b) Curved ribs

(c) Spars and ribs are covered with painted fabric

(3) Metal wings

(a) Construction similar to wooden wings, except ribs and covering are made of light metal

(b) Stronger, but heavier and more expensive than wood

(4) Attachment of wings to fuselage

(a) Full cantilever wing - very strong, can be attached directly to fuselage without external bracing, used mostly by military aircraft and commercial airliners

(b) Semicantilever wing - internal structure of wing lighter, streamlined wires or tie rods connect wing to fuselage

(c) Externally-braced wing - lightest of wing structures, struts or spars extend from wing to fuselage, used mainly by slow-flying aircraft, sporting, etc.

d. Empennage (Tail section)

(1) Vital for stability

(2) Components

(a) Horizontal stabilizer - fixed front section, provides longitudinal stability

(b) Elevator - hinged rear section, controls angle of attack, hence controls speed

(c) Vertical stabilizer (fin) - fixed front section, helps maintain desired direction of flight

(d) Rudder - hinged rear section, offsets adverse yaw

e. Hydraulic system

(1) Pascal's Law - pressure exerted anywhere on a confined fluid is transmitted undiminished to every portion of the vessel containing the fluid

(2) Mechanical advantage

(3) Operates brakes, lowers landing gear, extends and lowers flaps, controls propeller pitch

f. Electrical system

(1) Operates radios, navigation equipment, lights, etc.

(2) Generator charges storage batteries

(3) Magnetos provide current which ignites fuel mixture, keeping jet or propeller aircraft engines working

(4) Electric motors help pilot start engines, operate many mechanical devices, and perform numerous tasks where power is needed

g. Landing gear

(1) Main functions

(a) Assist take-off

(b) Absorb shock of landing

(2) Fixed or retractable - retracting reduces drag

(3) Shock absorbers - oleo strut

(4) Brakes

(a) Operate independently for right and left main gear

(b) Antiskid prevents locking

(5) Types of landing gear

(a) Conventional

(b) Tricycle

(c) Bicycle

3. ORIENTATION:

a. An airplane structure is a combination of related parts, frameworks, and assemblies, all grouped into a heavier-than-air

flying machine. To fly, it must have an aerodynamic shape. This shape must be made of parts having a high strength-to-weight ratio and having balance for flight. To be safe, the aircraft structure must withstand more force than just that imposed by its own weight. In general, airplanes are designed to withstand one and one-half times the full or maximum expected force.

b. This is the practical portion where the theory, principles, forces, and controls actually take shape. The student should recognize this relationship and realize that aircraft design and structure is the functional application of the areas studied earlier.

4. SUGGESTED KEY POINTS:

a. Man did not fly sooner because he did not have an adequate engine. After one was devised, it more than kept pace with the changes in the airplane structure. Our main concern at this point is that the engine is necessary and capable of producing sufficient thrust to sustain flight. However, the size, weight, and shape of the engine are important because they influence aircraft design and construction.

*V-9005, pp 30-31
**V-9013, pp 108-109
**V-9118, pp 168-169
**V-9156, pp 31-37
*V-9156, p 49

b. The cowlings and nacelles which cover the engine not only protect the engine, they also reduce drag by streamlining the aircraft.

**V-9118, pp 167, 170-171
***V-9162, pp 1-9-10

c. Many students have looked out the window of an airplane in flight and noticed that the wings flexed. Airplanes are flexible, that is, a certain amount of movement in the airplane is expected and desirable. Because the craft is constantly being subjected to air currents and bumps of varying intensity and direction, some flexibility is necessary in order to prevent structural failure.

*V-9013, pp 84-86
***V-9065, p 28

d. The five stresses which all aircraft undergo constantly while in flight are tension, compression, bending, shear, and torsion. To a lesser degree, the students' automobiles, bikes, and skate boards undergo the same stresses.

**V-9013, pp 87-88
***V-9065, pp 24-27
**V-9118, p 8
**V-9156, pp 54-57

e. The fuselage does much more than serve as a compartment to carry things. It must be strong enough to support all the other aircraft components and withstand exceedingly large stresses. Therefore, a knowledge of trusses and stressed skin designs is very important to the aircraft builder.

**V-9013, pp 95-99
***V-9118, pp 142-146

f. The primary lifting airfoil of an airplane is the wing. Wings are attached to an airplane in a variety of locations and ways - full cantilever, semicantilever and externally braced.

*V-9005, pp 26-28
**V-9013, pp 88-95
***V-9118, pp 147-153
**V-9156, pp 40-46

g. Empennage, or tail assembly, of an airplane is composed of several parts, each of which has a definite control function. Structurally these parts resemble wings, but are much less complex. The student should understand the following basic control functions.

**V-9013, pp 105-108

(1) Horizontal stabilizer - helps to provide longitudinal stability

(2) Elevator - controls angle of attack or pitch

(3) Vertical fin helps maintain direction of flight

(4) Rudder - compensates for yaw in turning

h. Hydraulics are only one of many systems which use a mechanical advantage to help the pilot operate and control the aircraft. Quite obviously, a C-5 pilot could not manually raise and lower the flaps and the 28 wheels on the landing gear. On today's aircraft, electrical motors are replacing hydraulics for many functions. The electrical motors use the same principles of mechanical advantage.

***V-9118, pp 9-10, 14-16, 18-20, 182-188

i. In addition to the basic conventional, tricycle, and bicycle landing gear, some aircraft use pontoons or the fuselage to land on water while others land on snow and ice using skis. All systems must cushion the landing shock and still reduce friction sufficiently for takeoffs so the aircraft can become airborne.

**V-9005, pp 29-31
***V-9013, pp 99-105
*V-9118, pp 155-156
***V-9156, pp 50-53

5. SUGGESTIONS FOR TEACHING:

a. Suggested time: 2-3-3

b. Because in this unit we are examining the aircraft itself, we need to see the relationships of its structures and how they fit together. Keep in mind the major principles already stated, and try to get the student to apply these principles to his new learning experiences. One approach is to lead the student through assigned readings and have him bring discussion questions

to class. A good guided discussion would certainly promote more learning than lecturing or other methods.

c. For this chapter, an understanding of your students' interests and abilities is essential. While some students will be bored and disinterested, for some students this could be the most interesting part of the text. If you recognize a specific interest in individual students, you should make an effort to individualize the method of instruction for them. They could be assigned time-consuming construction or drafting projects and reduce their homework requirements for other areas.

d. You may want to spend some time on mechanical advantage. Students are almost always interested in demonstrations of the pulley, lever, gear, and the inclined plane. (Also, you may want to point out that the man on the left in Figure 63 lacks intelligence in two ways. Not only is he not using a lever, he's also using an incorrect lifting technique which could lead to a hernia.)

e. Comparisons with familiar items are always effective. For example, (1) the landing gear can be compared to an automobile's shock absorbers, (2) the aircraft hydraulic and electrical systems also have automotive counterparts, (3) some cars now have antiskid (why?), (4) knives, grinders, can openers, etc., offer excellent examples of stresses, and (5) a wrecked automobile (there's probably one in the auto shop) offers a graphic description of stresses.

f. Your more advanced students might be assigned some computation problems. They could compute the amount of work done by a lever or a hydraulic system. If you want to impress them, merely mention that an aircraft hydroplanes when its speed equals nine times the square root of the tire pressure. Then ask them to compute the speed their automobiles would hydroplane (Question 5, page 105 of the text).

g. Answers to Chapter VI Questions:

(1) d. all of the above

(2) engine protection, aids engine cooling

(3) streamlined containers for auxiliary engine systems

(4) fuselage

(13) false spar

(14) a. 3 b. 2 c. 1

(15) to give more stability

(16) a. 2 b. 1 c. 1

(17) six pounds

(5) a. 4 b. 5 c. 1 d. 2 e. 3

(6) true

(7) false

(8) light; strong; rigid

(9) semimonocoque

(10) the load placed on the aircraft in flight

(11) a. maximum applied load

(12) a. 2 b. 2 c. 1 d. 2 e. 1

(18) two inches

(19) refer to textbook section on electrical systems

(20) less

(21) oleo struts

(22) antiskid

(23) b. tricycle

(24) bicycle

h. Student text assignment: read pages 85-107.

6. INSTRUCTIONAL AIDS

a. Films:

(1) USAF

TF-1-5300 Beyond the Stick and Rudder, 14 min., B&W, 1959. **

TF 6332 Hydraulic Brakes - Principles of Operation, 22 min., B&W, 1967. **

(2) FAA

FA-602 A Plane Is Born, 27 min., color, 1968. **

FAC-135 The Wind Is Right, 28 min., color, 1971. ***

FA-807 Plane Sense, 20 min., color, 1968. *

b. Transparencies

V-1001 Airplane Components

V-1004 B-2, Tail Structure (not furnished after 1971)

V-1052 Basic Hydraulic Fluid System

7. PROJECTS:

a. See page 105 of the text.

b. Build an airplane! Not as far fetched as it sounds. Naturally it should be done through the industrial arts department. Plans are available from the Experimental Aircraft Association, Air Education Museum, P. O. Box 229, Hales Corners, Wisconsin 53130.

c. Build a Warren Truss as a shop project and test its strength. On a smaller scale, it can be constructed with toothpicks and glue.

d. Invite an FAA Inspector to explain to the class what he looks for when making airworthiness inspections.

e. Several aircraft systems such as spark plugs are duplicated (redundancy). Have your students discuss this.

f. Construct aircraft models of various aircraft. Have students report on the construction features.

8. FURTHER READING:

a. See page 105 of the text.

b. Aircraft in Flight, CAP.

c. Aerospace magazine.

d. Aviation Week and Space Technology (December 12, 1974, pp 48-49).

e. The TUSC News.

NOTE: Refer to "Aircraft Design Calculations," a supplement to this handbook by Lt Colonel Darreld K. Calkins, USAF (Retired), Wilson High School, Florence, South Carolina (SC-51). This supplement is intended to integrate the materials taught in this text with more advanced aeronautical technology. Use it as a challenge for your more advanced students.

IDEAS FOR IMPROVEMENT OF THE TEXTBOOK AND/OR INSTRUCTOR'S GUIDE
AND TEACHING TECHNIQUES MOST EFFECTIVE FOR THIS CHAPTER.
TO BE COMPILED AT END OF TEXT AND SENT TO JRC

THEORY OF AIRCRAFT FLIGHT

CHAPTER VII - AIRCRAFT INSTRUMENTS

This chapter introduces the student to aircraft instruments. After the student learns about classifying instrument systems, he can then examine selected instruments and their operation. Because later units examine some of these instruments in depth, this chapter provides only a quick look at the entire instrument panel with emphasis on flight control instruments. The student should finish the chapter knowing why aircraft have instruments and what information the pilot derives from them.

1. OBJECTIVES:

   a. Traditional - Each student should:

      (1) Know two ways in which aircraft instruments are classified and one example of each group.

      (2) Know what each class of instruments does and how it works.

      (3) Know how at least three flight control instruments are used.

   b. Behavioral - Each student should be able to:

      (1) Outline two ways in which aircraft instruments are grouped and give at least one example for each group.

      (2) Describe what each class of instruments does and how it works.

      (3) Discuss how at least three flight control instruments are used.

2. SUGGESTED OUTLINE:

   a. Aircraft instruments are no more complex to a pilot than auto instruments are to a driver.

   b. Early instruments

      (1) Airspeed measured with wind gauges

      (2) Didn't really need altimeters and navigation instruments

      (3) Early fuel gauge

      (4) Early attitude indicator

c. Instrument classification

(1) By usage

(a) Engine

(b) Navigation

(c) Flight

(2) By principle of operation

(a) Mechanical - gyroscope operation

(b) Pressure

(c) Electrical

d. Engine instruments and what they indicate

(1) Tachometer - engine speed (RPM)

(2) Temperature gauges - oil, cylinders, carburetor intake

(3) Pressure gauges - oil, fuel, manifold

(4) Fuel quantity gauges - fuel supply

e. Navigation instruments and what they indicate

(1) Airspeed indicator - airspeed

(2) Altimeter - altitude

(3) Compass - determines direction of flight based on 360° circle

(4) Clock - measures time

f. Flight instruments and what they indicate

(1) Altimeter - altitude

(2) Airspeed indicator - airspeed

(3) Turn and bank indicator (needle and ball) - evaluation of a turn in flight

(4) Rate of climb indicator - gain or loss of altitude

(5) Artificial horizon - attitude of aircraft

3. ORIENTATION:

a. The pilot cannot adequately and accurately sense all of the conditions of his aircraft and of flight. Engine status, aircraft attitude, and component information must be measured and clearly indicated. These readings must be extremely accurate and readily available to the pilot. The pilot is absolutely dependent on these instruments for safe operation of the engine and powerplant.

b. Emphasis is on flight instruments because navigation and pressure instruments are covered in other texts.

4. SUGGESTED KEY POINTS:

a. While they look complex, aircraft instruments are really quite simple and generally easily read once they're understood. Also, in multiengine aircraft, engine instruments are duplicated for each engine. Referring to the center cluster of instruments in Figure 65A, there are really only eight instruments but they're duplicated four times. This cluster system makes it very easy to detect a malfunction on one engine. If only instrument is different, check further.

**V-9162, p 11

b. Aircraft instruments are classified in terms of their use or in terms of the principle underlying their construction. Throughout your lesson, stress that what the instrument tells the pilot is more important than how it works. Later in the course, if appropriate, the occupational field of instrument repair and design can be discussed.

***V-9118, pp 244-270

(1) Engine instruments have only one function, to let the pilot know how the engine is operating. For the reciprocating engine, the tachometer, temperature gauges, pressure gauges, and fuel quantity gauges are generally basic. A beginning student may feel too much stress is placed on engine instruments until you point out that, unlike a car, you can't pull over and park when the engine quits.

***V-9005, pp 59-60
***V-9161, pp 2-28, 2-33-36
**V-9162, p 15

(2) Navigation instruments are primarily to keep the pilot from getting lost. These will be discussed in more detail in the navigation text.

**V-9187, pp NAV-1-2, RN-1-4

(3) Flight instruments aid the pilot in establishing the attitude of the aircraft. An experienced pilot with the aid of some navigation

***V-9002, pp 236-237

instruments, need never see the outside of the aircraft except for takeoff and landing.

c. Several flight instruments use gyroscopes in order to maintain a constant reference point even when the aircraft is executing acrobatic maneuvers. For this reason, the rigidity in space feature should be emphasized as well as the fact that outside disturbances such as magnetism do not influence its functioning.

***V-9118, pp 271-280
**V-9156, pp 156-161
***V-9162, p 17
***V-9187, FL-13-14

d. A properly banked level turn with the forces in balance is a coordinated turn. The pilot uses the needle and ball (turn and bank indicator) to determine whether or not he is making a proper turn. Rate of turn may also be gained from the artificial horizon.

***V-9090, pp 76-77
**V-9156, pp 164-165
***V-9162, pp 54-57
**V-9166, pp 92-94
***V-9187, FL-13-17

e. Many instruments aid the pilot in determining whether or not he is changing altitude, but the two primary instruments are the rate of climb (vertical speed) indicator and the artificial horizon. Using the artificial horizon, the pilot can quickly tell the aircraft's attitude whether he is turning, climbing, or descending.

**V-9002, pp 227-228
***V-9005, pp 61-62
**V-9161, p 2-16
***V-9187, p FL-7

5. SUGGESTIONS FOR TEACHING:

a. Suggested time: 1-2-2

b. The depth and method of instruction will depend primarily on how well your students have grasped the principles of flight taught in Chapters I, III, IV, and V. Opening with a review of the four forces of flight and aircraft motion and control is appropriate. You might ask your students which of the four forces apply to a baseball pitcher's curve ball and then ask them to explain how. Most of them will quickly recognize thrust, drag, and weight. Some will say lift, but few will realize that it's pressure differential lift that causes the ball to curve. Because the ball is spinning, the relative wind is faster on the side rotating forward, thereby reducing the pressure and lifting (displacing) the ball in that direction.

c. You should use a "hands on" approach for this chapter. A flight simulator is the best possible instructional aid for this chapter. A poor man's alternative is transparency V-1011. An excellent approach is to turn off the overhead, adjust the instruments, then turn it back on and have the students identify the aircraft's attitude, speed, altitude, etc.

d. This chapter presents an outstanding opportunity to review and reinforce the forces experienced in a turn studied in Chapter V. Here again, you can use V-1011 and ask the students to draw the correct turn vectors and resultants based on the instrument readings.

e. The most effective way to explain a gyroscope and its characteristics is to actually operate a gyroscope. If you do not have one, the science department will almost surely be able to loan you one. A word of caution, your students may well have already studied gyroscopes recently and you then will merely want to cover its importance to a study of aircraft instruments.

f. Instrument and control arrangement in the cockpit is a science in itself. A brainstorming session on where all the things in the cockpit should best be located should generate a lively discussion.

g. Answers to Chapter VII Questions:

(1) true

(2) piece of string

(3) engine, navigation, flight

(4) gyroscopic

(5) rigidity in space and precession

(6) false

(7) a. temp. b. pres. c. both d. temp. e. pres.

(8) prevent fuel starvation, better lubrication

(9) navigation instrument

(10) airspeed indicator and altimeter

(11) lowest bank for the rate of turn

(12) g, f, h, e, a, i, b

(13) rate of climb indicator, airspeed indicator, artificial horizon, altimeter

h. Student text assignment: read pages 109-120

6. INSTRUCTIONAL AIDS:

a. Films:

(1) USAF

TF-1-5342A Instrument Flying Techniques - Basic Instruments, 30 min., B&W, 1961. *

(2) FAA

FA-06-71 Dusk to Dawn, 28 1/2 min., color, 1971. **

FA-09-03 Disorientation, 19 min., color, 1973. **

FA 704 Stable and Safe, 20 min., color, 1969. **

b. Transparency

V-1011 Flight Instruments

c. Miscellaneous

(1) Gyroscope (V-2010)

(2) Flight Simulator (see page 46 this handbook)

(3) Homemade simulator - plans for building one plus a set of printed instrument faces can be purchased for approximately $2.00 from: R. Brownsberger, 72 Parkway Avenue, Markham, Ontario, Canada

7. PROJECTS:

a. See pages 120-121 of the text.

b. Have a school photographer take pictures of actual aircraft instruments and use them for display purposes.

c. Get instruments from the base salvage depot.

d. Paint instruments on the bottom of No. 10 cans.

e. Invite an airline pilot as a guest speaker on instruments in the modern aircraft.

8. FURTHER READING:

a. See page 121 of the text.

b. Aircraft in Flight, CAP.

c. AFM 51-37, Instrument Flying

d. AFM 51-40, Air Navigation

e. Private Pilot's Handbook of Aeronautical Knowledge, FAA (AC 61-23)

f. VFR Exam-O-Gram No. 45, "Airspeeds and Airspeed Indicator Markings"

g. Commander's Digest, Vol. 16, No. 7, August 15, 1974, "How Simulators Aid Service Training."

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